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The "Spinal Metastasis Invasiveness Index": A Novel Scoring System to Assess Surgical Invasiveness

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Mini Abstract / Precis:

The spinal metastasis invasiveness index (SMII) is comprised of surgical factors, tumor vascularity and preoperative embolization, which is able to predict long operative time and high blood loss in patients undergoing metastatic spine tumor surgery. SMII can be a tool to assist in resource planning, allocation, and patient education.

Abstract

Study Design: Retrospective review

Objective: To develop a surgical invasiveness index for metastatic spine tumor surgery (MSTS) that can serve as a standardized tool in predicting intraoperative blood loss and surgical duration; for the purpose of ascertaining resource requirements and aiding in patient education.

Summary of Background Data: Magnitude of surgery is important in the metastatic spine disease (MSD) population since these patients have a continuing postoperative oncological process; a consideration that must be taken into account to maintain or improve quality of life. Surgical invasiveness indices have been established for general spine surgery, adult deformity, and cervical deformity, but not yet for spinal metastasis.

Methods: Demographic, oncological, and procedural data were collected from consecutive patients that underwent MSTS. Binary logistic regression, using median values for surgical duration and intraoperative estimated blood loss (EBL), was used to determine statistical significance of variables to be included in the "spinal metastasis invasiveness index" (SMII). The corresponding weightage of each of these variables was agreed upon by experienced spine surgeons. Multi-variable regression analysis was used to predict operative time and EBL while controlling for demographical, procedural, and oncological characteristics.

Results: Two hundred and sixty-one MSD patients were included with a mean age of 59.7-years and near equal gender distribution. The SMII strongly predicted extended surgical duration (R^2=0.28,p<0.001) and high intraoperative blood loss(R^2=0.18,p<0.001). When compared to a previously established surgical invasiveness index, the SMII accounted for more variability in the outcomes. For every unit increase in score, there was a 42 mL increase in mean blood loss (p<0.001) and 5-minute increase in mean operative time (p<0.001).

Conclusions: Long surgical duration and high blood loss were strongly predicted by the newly developed SMII. The use of the SMII may aid in preoperative risk assessment with the goal of improving patient outcomes and quality of life.

Keywords: Blood loss; Operative time; Invasiveness index; Spine metastasis; Surgical invasiveness; Tumor surgery; Spine tumor

Level of Evidence: 4

INTRODUCTION

The spine is the leading site of skeletal metastases that originate from a wide range of primary tumors that include lung, breast, prostate, kidney, and thyroid. [1,2] A vast spectrum of spinal involvement and radiologic patterns can lead to severe neurological compromise, debilitating pain, and spinal instability. Metastatic spine tumor surgery (MSTS) presents a challenge to the treating surgeon as preoperative planning must consider health status, prognosis, prior radiotherapy (RT) and/or chemotherapy, primary tumor type, extent of disease, and spinal alignment. [3-5] The goals of MSTS pivot around adequate decompression of neural elements and conferring vertebral column stability; the different techniques and approaches to achieve these contribute to variable clinical outcomes and complications. [4] MSTS differs from other spinal surgeries as patients have a continuing postoperative oncological process; a consideration that must be taken into account to maintain quality of life. Complications such as extended length of hospital stay, unplanned readmissions, and unique adverse events such as recurrence of neurologic deficit from rapid tumor regrowth and construct failure in pathologic bone, differ greatly from those found in degenerative spine conditions. [2,6-8]

The variability in surgical treatment of similar metastatic spinal disease (MSD) cases across different institutions can be attributed to a lack of universal treatment algorithms. An objective index would be useful to predict important outcomes in MSTS such as blood loss, operative time, postoperative complications, and length of hospital stay to help patients make informed decisions about their proposed surgeries. Additionally, such an index would allow comparison between surgical outcomes within and between different spine centers treating MSD. Mirza et al [9] was the first to develop such an index for spine surgeries wherein a point value was assigned to each component of the procedure. The sum of the components became the total surgical invasiveness score which was validated to assess surgical duration and intraoperative blood loss. Similar indices have been developed for both adult spinal deformity and cervical deformity procedures. [10,11] However, these scoring systems are biased towards predicting invasiveness for degenerative spinal deformities and are inappropriate for MSTS.

No studies to date have developed an invasiveness index specific to the metastatic spine population. Therefore, we aimed to develop a surgical invasiveness index for spinal metastasis with internal validation by evaluating its association with blood loss and operative time. We selected these outcome measures as they have been closely linked with the magnitude of surgery and can be quantified objectively. [9-12]

METHODS

We conducted a retrospective review of MSTS patients in our institution between 2005 and 2015. Institutional Review Board approval was obtained before study commencement. We included all metastatic spine patients that underwent surgical procedures and had follow-up data up to 1 year or until their demise. Inclusion criteria were patients $\geq$ 18 years with radiological and histological evidence of MSD. Patients with isolated vertebroplasty, active/healed spinal infections or exposure to high energy trauma preceding surgery were excluded.

Demographic and clinical data collected included patient age, sex, BMI, Charlson Comorbidity Index (CCI), and European Cooperative Oncology Group Performance (ECOG). Oncologic data acquired included primary tumor type, extent of metastases (i.e. visceral and vertebral), levels of cord compression, preoperative and/or postoperative RT and preoperative embolization. Surgical data collected included operative time, estimated blood loss (EBL), surgical approach, levels of instrumentation, and levels of decompression.

Development of the Spinal Metastasis Invasiveness Index

The components considered for inclusion in the index were derived from the previously published study by Mirza et al. [9] We decided to use operative time and EBL as direct measures of surgical invasiveness and forewent length of hospital stay, adverse events, and unplanned readmission as these could be due to the sequelae of patients' oncological disease process and not surgical invasiveness itself. Patient and operative variables predicting high operative time and EBL based on their medians (operative time >230 minutes, EBL >650 mL) were evaluated using binary logistic regression. Variables that were significant in the binary logistic regression were considered for the development of the index. Experienced spine surgeons were consulted and reached a consensus on the selected weightage for each variable to create the "spinal metastasis invasiveness index" (SMII). Multivariable regression analysis was used to predict operative time and EBL while controlling for demographical, procedural, and oncological characteristics. SPSS version 23 (Armonk, NY) was used for all statistical analyses and significance level was set at 0.05.

RESULTS

A total of 261 MSTS patients with complete baseline demographic, clinical, surgical details and follow-up data were included. Mean age was 59.7 ± 11.5 years and 50.6% of the cohort were female (Table 1). Patients had a median CCI of 7 and average preoperative ECOG score of 1.3 ± 1.0. The cohort had an average of 6.2 ± 2.9 levels instrumented and 1.8 ± 1.3 levels decompressed, with 12.3% anterior-only surgeries, 76.6% posterior-only, and 11.1% combined. Average EBL was 824.5 ± 685.4 mL, and average operative time was 253.4 ± 113.3 minutes. Majority of tumors were from a lung primary (30.3%), followed by breast (18.6%) and prostate (8.9%) (Table 2).

Spinal Metastasis Invasiveness Index

The variables included in the newly developed SMII (Table 3) with their corresponding weightage were: total corpectomy from any approach (4 per level), hemicorpectomy from any approach (3 per level), pediculectomy (2 per pedicle), posterior decompression (2 per level), anterior column support i.e. cement spacer, graft and cage (2 per level attached to and replacing vertebral bodies), open posterior instrumentation (2 per level), posterior percutaneous surgical fixation (PPSF) (1 per level), and vertebroplasty (1 per level). These variables were carefully chosen to reduce any interobserver ambiguity as each operative procedure can be dissected into these above mentioned operative components.

The SMII is a tool primarily developed to predict blood loss and operative time. Of all the preoperative variables, tumor vascularity and embolization would have the largest influence on blood loss. [13,14] Hence, we decided to include only the above 2 factors as modifiers. Hypervascular tumors (i.e. renal, thyroid, hepatocellular, etc.) were awarded a modifier of 2 per level decompressed, separately scored for anterior and posterior column. Similarly, for absence of preoperative embolization, we awarded a modifier of 1 per level, separately scored for anterior and posterior column.

The newly developed SMII predicted high intraoperative blood loss (R^2=0.18, p<0.001), and extended operative time (R^2=0.28, p<0.001). When compared to the Mirza et al [9] index (Table 4), the SMII accounted for more variability in both outcomes. The SMII explained 18% of the variation in EBL as against 13% by Mirza et al.'s [9] index; similarly, SMII explained 28% of the variation in operative time as against 14%. For every 1-point increase in the SMII score, there was a 42 mL increase in mean blood loss (p <0.001) and 5-minute increase in mean operative time (p<0.001).

Case Examples

Figure-1 presents preoperative and postoperative radiographs for a patient who underwent an uncomplicated PPSF from T11 to L3. The spinal instability neoplastic score (SINS) of the patient was 12 and the modified Tokuhashi score was 13. The scores based on the surgical invasiveness index of Mirza et al [9] and newly developed SMII were both 4. The EBL was 50 mL and operative time was 146 minutes.

Figure-2 presents preoperative and postoperative radiographs for a patient who underwent an uncomplicated anterior L2 corpectomy with cage support and PPSF from T12 to L4. The SINS of the patient was 14 and the modified Tokuhashi score was 11. The patient had renal cell carcinoma but had preoperative embolization. The score based on the Mirza et al [9] index was 10 while the score using the newly developed SMII was 16 (i.e. 4 points for one level corpectomy, 2 points for the hypervascular tumor modifier, 6 points for use of anterior expandable cage, 4 points for 4 levels of MIS posterior instrumentation). The EBL was 610 mL and operative time was 226 minutes.

Figure-3 presents preoperative and postoperative radiographs for a patient who underwent an open posterior instrumentation from T2 to T11 and subsequent anterior T6 to T8 corpectomies with reconstruction. The SINS of the patient was 12 and the modified Tokuhashi score was 8. This patient suffered from lung adenocarcinoma and was not embolized preoperatively. The invasiveness score according to Mirza et al [9] was 16 while our score using the SMII was 39 (i.e. 14 points for open posterior instrumentation, 12 points for 3 corpectomies plus 3 points for no embolization, 10 points for anterior support). The EBL was 2700 mL and operative time was 396 minutes.

DISCUSSION

The SMII was envisaged to predict EBL and operative time for MSTS, better than a previously established invasiveness index for general spine surgery. Intraoperative blood loss and surgical duration have been shown by numerous studies [9-12] to be associated with extensive spinal surgeries and are logical, quantifiable markers of surgical invasiveness. By refining the components of the surgical invasiveness index of Mirza et al, [9] we have developed a novel SMII specifically tailored to patients with MSD that was able to successfully predict the magnitude of surgery.

Recently, a novel cervical deformity surgical invasiveness index utilized length of stay as another outcome measure. [11] We acknowledge that this is applicable to MSTS patients as extended hospital stay reflects longer recovery from complex spinal procedures and accounts for occurrence of postoperative complications. [6,15] Similarly, Zaw et al. [16] highlighted that operative parameters such as EBL and length of surgery may considerably influence the risk of postoperative complications after MSTS. Therefore, SMII may be considered as an indirect predictor of the risk of postoperative complications such as urinary tract infections, pneumonia, or deep vein thrombosis. Nonetheless, MSTS patients are a unique population whose primary oncological process continues even after successful and uneventful spinal surgery. Numerous sequelae from other organ systems affected by their cancer can manifest postoperatively and affect length of hospital stay and the risk of postoperative medical complications. [17] Hence, directly associating our index with the length of hospital stay or the risk of postoperative complications may obscure the true effect of surgery on these parameters. This same principle applies to other measures of surgical outcome in MSTS such as unplanned hospital readmissions.

We understand that multiple factors can influence operative time and intraoperative blood loss in MSTS. Renal, thyroid, hepatic and other primary cancers tend to produce hypervascular metastatic lesions that bleed profusely, leading to increased intraoperative blood loss and operative times. [14] Conversely, preoperative embolization is known to reduce blood loss and hasten decompression. [13] Hence, we decided to include these variables to calculate the index as it makes the SMII more comprehensive.

Other indices such as those of Neuman et al. [10] and Passias et al. [11] dealing with adult spinal deformity and cervical deformity, respectively, are justified in their use of radiographic measurements. Larger and more extensive deformity corrections are reasonably associated with a higher degree of invasiveness and surgical complexity. [18] However, MSTS patients usually present with neurological deficits or pain that preclude them from obtaining full length standing radiographs. In addition, MSTS patients have a low overall mean survival of • 10 months [18-20] with decreased physiologic demands or functional status in the postoperative period. For these reasons, we deemed it unnecessary to include angular measurements pertaining to global and regional sagittal alignment in our invasiveness index.

Variables such as age, CCI, ECOG and neurological status, were also not included in the scoring system as these variables did not significantly predict both increased EBL and prolonged surgical duration in binary logistic regression analysis. Mirza et al. [9] highlighted that although age, comorbidities and neurological status influence blood loss and duration of surgery, they account for only about 1%–5% of the variation. Furthermore, inclusion of these variables would render the SMII too complex, thereby, limiting its utilization. As a whole, one of our primary objectives was to produce a system where scores would be simple to calculate as in the scoring system by Mirza et al., [9] but still account for more variability in operative time and blood loss in MSTS. However, we believe that the SMII can be used in conjunction with other established scoring systems that include patient factors and address health related quality of life, to better tailor the surgical procedure to the patient.

There are no other studies that have attempted to apply a surgical invasiveness index to patients with MSD. MSTS has different aims of care than patients undergoing surgery for degenerative spinal conditions; wherein the most important being the maintenance or improvement of quality of life. In addition, it alleviates spinal symptoms and provides local control of the tumor. Ultimately, surgery in MSD will never achieve total cure of the primary cancer, hence meticulous planning is needed to assure the best possible outcomes. Metastatic spinal decompression and reconstruction are, for the most part, challenging and technically difficult, hence factors to assess surgical invasiveness are likely to be different than those used for the general spine population.

The study of Mirza et al [9] included a case mix of spinal conditions in their cohort which included degenerative, trauma, tumors, infections and revisions. Tumors accounted for only 7.4% of the entire cohort and it was unclear whether they were metastatic or primary in nature. The development of SMII specific to MSD is important to aid in preoperative planning and risk assessment of this fragile population. Patients undergoing MSTS have poorer health status than those with degenerative conditions as highlighted by the higher scores (CCI mean: 7.3 ± 1.4) compared to that of studies investigating deformity invasiveness indices (CCI mean: 2 ± 2). [9,10] MSTS patients can present with multiple symptomatic vertebrae at different regions along the spinal column, which can cause difficulty in prioritizing and staging of surgery. Intraoperatively, decompression of pathologic vertebral elements carries a higher risk of increased blood loss that can indirectly lead to a longer procedure. Fusion in MSTS constructs is also seldom performed and only suitable in patients with good prognosis and projected long-term survival. We believe there is value in a scoring system to predict magnitude of surgery in patients where there is a wide range of preoperative considerations.

Efforts to improve the accuracy of predicting quantifiable outcomes of surgery are likely to improve patient safety, quality of life, and efficiency of spinal care. With MSTS involving • 4 levels of spinal instrumentation and • 1 level of decompression, there is considerable risk of complications. MSTS is associated with a 29% risk of complications, [21] but the reports range from 10 to 66.7% in existing literature. [22] The utility of an invasiveness index would allow surgeons to adequately prepare for their interventions based on the patient's preoperative status. High scores can signal providers to consider appropriate resource planning for extensive surgery, optimizing general condition of the patient, and performing neoadjuvant treatments. Conversely, lower scores would favor early surgery to address potential vertebral instability or to separate neural elements from pathologic tissue for subsequent radiation therapy (i.e. separation surgery). [23,24] In addition, this index would assist in proper resource management and allocation in terms of anesthetic support, blood product management, and pre-booking of intensive care units. [16,25]

Limitations

The retrospective review of patient data for this study could potentially introduce selection and information bias. A prospective study may be needed to further validate our study findings. We relied on the data of patients that spanned over a period of 10 years where surgical techniques have evolved especially in the field of MSD. Despite the limitations stated above, our cohort only contained patients who underwent MSTS which was different from the study by Mirza et al. [9] which included patients from the full spectrum of spinal surgery. This might theoretically limit the comparisons made between the two indices. This does, however, highlight the need for a separate invasiveness index specific for MSTS. The SMII developed in this study only explains trends in EBL and operative time but cannot predict the actual numeric values of these outcomes. This could be attributed to other factors in MSTS that could potentially contribute to its invasiveness.

CONCLUSION

Ours is the first study to date to develop a novel "surgical invasiveness index" specific to the metastatic spine tumor population. Surgical duration and blood loss were strongly predicted by the newly developed "spinal metastasis invasiveness index" (SMII), incorporating surgical factors clinically relevant for patients undergoing MSTS. The SMII accounted for more variability than the previously established invasiveness index. This index will allow surgeons to gauge the intraoperative blood loss and surgical duration of their proposed procedures, aiding in resource management. Additionally, this will indirectly improve risk assessment of patients undergoing MSTS.

Key Points

1. An invasiveness index for spinal metastasis is important to assess magnitude of surgery which may have repercussions on the continuing oncologic process that these patients still must contend with postoperatively.
2. The spinal metastasis invasiveness index (SMII), which is comprised of surgical factors, tumor vascularity, and embolization status, strongly predicted increased operative time and intraoperative blood loss.
3. This index can assist in proper resource management and allocation in terms of anesthetic support, blood product management, and pre-booking of intensive care facilities for this already fragile population.

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Figure 1: *Preoperative and postoperative images of a patient who underwent minimally invasive T11 to L3 posterior instrumentation for symptomatic and potentially unstable L1 metastasis of the cervix.*

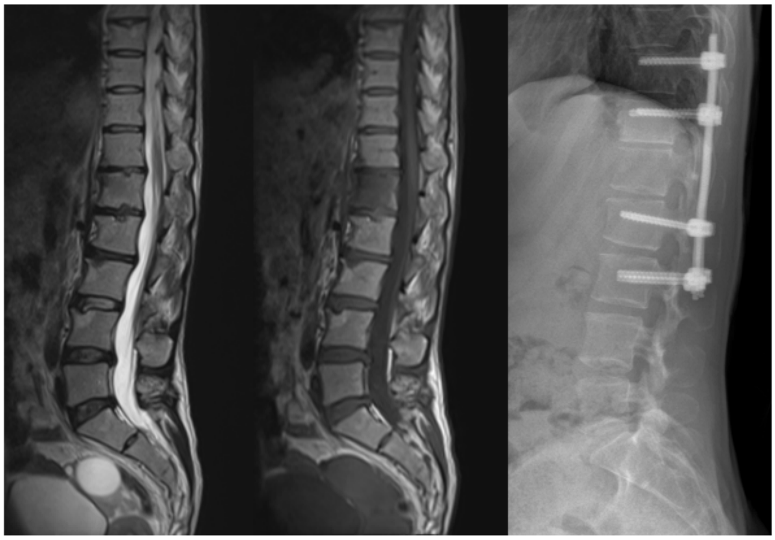

Figure 2: *Preoperative and postoperative images of a patient who underwent minimally invasive T12 to L4 posterior instrumentation with anterior reconstruction for an L2 pathologic fracture secondary to metastatic renal cell carcinoma.*

Figure 3: *Preoperative and postoperative images of a patient who underwent open T2 to T11 posterior instrumentation and T6 to T8 corpectomies with anterior support for metastatic lung adenocarcinoma.*

Tables

Table 1. Baseline Demographic, Clinical, and Surgical Details for MSTS Patients.

Demographic Variables	**Mean ± standard deviation or N (%)**
Age, years	59.7 ± 11.5
Gender, female	132 (50.6%)
BMI, kg/m2	23.2 ± 4.8
CCI	7.3 ± 1.4
ECOG	1.3 ± 1.0
Surgical Variables	
Surgical approach	
Anterior	32 (12.3%)
Posterior	200 (76.6%)
Combined	29 (11.1%)
Levels decompressed	1.8 ± 1.3
0	38(14.6%)
1-2	155 (59.4%)
3-4	58 (22.2%)
>4	10 (3.8%)
Levels instrumented	6.2 + 2.9
<6	127 (48.7%)
6-9	102 (39.1%)
>9	32 (12.2%)
Preoperative Embolization	58 (22.2%)
Outcomes	
Estimated blood loss, mL	824.5 ± 685.4
Operative time, min	253.4 ± 113.3

CCI - Charlson Comorbidity Index; ECOG - European Cooperative Oncology Group

Table 2. Baseline Oncologic Overview of 261 MSTS Patients.

Primary Tumor	**N (%)**
Lung	82 (31.4%)
Breast	45 (17.2%)
Prostate	25 (9.6%)
Thyroid	7 (2.7%)
Renal	20 (7.7%)
Gastrointestinal	20 (7.7%)
Nasopharyngeal	9 (3.4%)
Liver, Gallbladder	12 (4.6%)
Marrow	22 (8.4%)
Genitourinary tract	16 (6.1%)
Others	3 (1.1%)
Metastatic Profile	**N (%)**
Pathologic Fracture	161 (61.7%)
Previous RT	97 (49.3%)
Visceral Metastasis	79 (30.3%)
Vertebral Metastasis, levels	
1	60 (23.0%)
2	67 (25.7%)
• 3	134 (51.3%)
Cord Compression, levels	
0	10 (3.8%)
1	28 (10.7%)
2	86 (33.0%)
3	137 (52.5%)

Table 3. Components Used to Calculate the Spinal Metastasis Invasiveness Index (SMII).

Factors	**Points Assigned**
Total Corpectomy[a]	4 points per level
Hemicorpectomy[a]	3 points per level
Anterior column support (cement spacer / graft / cage)	2 points per level spanned in order to replace the vertebral body/bodies
Pediculectomy	2 points per pedicle
Posterior decompression	2 point per level
Posterior instrumentation	
Open	2 points per level
Minimally invasive	1 point per level
Vertebroplasty	1 point per level
Modifiers:	
Hypervascular primary tumor (i.e. thyroid, renal, liver, gallbladder)	2 points per level decompressed [a, b]
No preoperative embolization	1 point per level decompressed [a, b]

[a] Regardless of type of approach, [b] Count separate for anterior and posterior decompression

Table 4: Correlations of Surgical Invasiveness Indices with Estimated Blood Loss and Operative Time

Index	**Estimated blood loss**		**Operative Time**	
	Pearson correlation coefficient (r)	% of variability explained (R^2)	Pearson correlation coefficient (r)	% of variability explained (R^2)
Mirza et al	0.36	0.13	0.38	0.14
SMII	0.42	0.18	0.53	0.28